The positive-negative index coupled waveguide systems: couplers, arrays and bundles

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Abstract—The coupled electromagnetic waves propagating in a waveguide array, which consists of alternating waveguides of positive and negative refraction indexes, are discussed. The pair of positive-negative waveguides acts as oppositely directional coupler. The stop band in the spectrum of linear waves occurs. When pairs of these waveguides are collected in array or bundle the spectral properties of the resulted device are modified. We study spectral gaps in these waveguide systems and demonstrate that the number of waveguides and helical spatial twist of the array can be used to control the size of the gap.

I. INTRODUCTION

Negative refraction occurs in media in which the wave vector of the electromagnetic wave is antiparallel to the Poynting vector. For example, if the real parts of the dielectric permittivity and magnetic permeability in the medium simultaneously take on negative values in some frequency range, the property of negative refraction will appear.

The remarkable properties of negative refractive index (NRI) materials reveal themselves most prominently when a wave passes through or is localized near an interface between such a material and a conventional dielectric. The couplers and waveguide arrays are simplest example of the positive-negative refractive index devices.

II. COUPLED WAVEGUIDES SYSTEMS

A. Oppositely directional coupler

It has been known that two closely located waveguides can be coupled due to the tunneling of light from one waveguide to the other. If waveguides are fabricated from materials with a positive refractive index (PRI) then the wave propagation direction is unchanged. The coupler is named a directional coupler.

In linear regime two coupled waveguides with opposite signs of the refractive index act as a mirror. This device can be called the oppositely directional coupler (ODC). In this case the spectrum of linear waves has the forbidden zone (gap). However, if the input pulse power exceeds certain threshold, the steady state solitary wave can appear. The formation of a gap soliton in the ODC was investigated by the numerical simulation. In the case of the symmetric ODC (i.e., both waveguides possess the same nonlinear optical properties) the analytical approximate formula for the amplitude threshold is obtained.

B. Bundles and zigzag arrays of waveguides

The circular arrays of coupled waveguides (i.e., bundles) with alternating signs of the refractive index are considered. We considered the case there number of PRI waveguides is equal to number of the NRI waveguides. If the number of PRI waveguide pairs is odd, then the spectrum of linear waves has the gap, else there are gapless modes. We demonstrate how twist of the bundle can be used to control the gap width and the parameters of gap solitons. The expression for gap soliton propagating in the twisted bundles is obtained.

The zigzag configuration of the arrays of coupled waveguides is considered. Due to zigzag configuration there are interactions between both nearest and next nearest neighboring waveguides exist. It is shown that gap in the spectrum of linear waves and gap solitons are inherent in this waveguide system too.

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